# A Real Cost of Free Trades: Retail Option Trading Increases the Volatility of Underlying Securities *

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**Abstract**

We examine the link between retail trading in options and the volatility of the underlying assets. Using Robinhood's introduction of options as a shock to retail trading, we confirm that option volume increased around this event and show that volatility similarly increased for: interlisted US securities, relative to their Canadian counterparts; optioned shares relative to optionless shares for firms with dual class shares; and more so for shares that would be become more attractive to retail traders as a result of the fee change (relatively high stock prices or low option prices). We provide further evidence suggesting the effect is permanent and that the underlying mechanism is related to market makers hedging their option exposure: volatility increases more for shares with higher option-embedded leverage; spreads and price impacts are lower; market maker volumes increase; and the volatility of retail option volume increases. Our results suggest that a shift in retail trading toward options drives an increase in the volatility of the optioned securities due to the actions of market makers hedging their exposure.

**JEL Classification Codes:** G01, G12, G13, G14.

**Keywords:** Retail traders, Options, Robinhood, Volatility.

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# 1 Introduction

Retail traders are attractive market participants—they are plausibly uninformed about both underlying security values as well as the trading costs they might be incurring. Not surprisingly, therefore, market mechanisms are designed to increase retail trading either at the front end of the trading process, as with the recent proliferation of low-fee and no-fee trading platforms, or during that process, as with the long-standing practice of buying order flow. Motivated by the rise of such mechanism in options markets, recent research has shown how option market trading may be particularly harmful to retail traders as well as what impact retail trading has had on option market quality itself. We introduce and explore another possible outcome associated with increased retail trading of options: an increase in the volatility of the underlying securities.

Prior research has documented the fact that retail traders trade badly, pay high spreads, and exercise their options sub-optimally.[1] As to market quality, the impact of retail trading is yet to be fully understood. While uninformed retail trading may improve market quality by lowering (relative) adverse selection costs, herding and other behavioral biases may disrupt prices. In a particularly relevant recent paper, Eaton, Green, Roseman, and Wu (2022b) use disruptions in trading venues to explore the impact of retail trading on venue market quality. They conclude that the most inexperienced retail traders, who dominate the Robinhood platform and are more likely to herd, disrupt markets, while retail trading more generally leads to better quality. In particular, they show that disruptions in Robinhood trading, which lowers inexperienced trading, reduced volatility. We examine volatility induced by retail trading that arises not from their trading in the securities themselves, but from a an increase in their trading of options on the underlying securities.

A link between option trading and underlying securities could arise from price discovery in the option markets. However, a more direct link is suggested by Ni, Pearson, Poteshman, and White (2021). They argue that that option market makers hedging their net positions (gamma hedging) could transfer net price pressures from one market to the other since these dynamic hedging strategies entail buying (selling) the underlying asset when the option price increases (decreases).[2] In support of this mechanism, Ni et al. (2021) show that volatility is decreasing in net purchased options by investors who are most likely to be hedging. We conjecture that market makers hedging net purchases by retail traders could, therefore,

[1]See Bauer, Cosemans, and Eichholtz (2009), Bryzgalova, Pavlova, and Sikorskaya (2023), Ernst and Spatt (2022) and de Silva, Smith, and So (2022), among others.

[2]This relation is predicted by theoretical work (Frey, 2000; Wilmott and Schönbucher, 2000) for the hedging of illiquid securities. If markets are not sufficiently liquid to absorb this added volume, volatility will increase.

drive up volatility in the underlying securities. It is possible, of course, that this effect is mitigated in two ways: the impact of hedging would only affect volatility to the degree the underlying securities are not perfectly liquid, and there may be a reduction in retail trading to the extent volume is migrating from one market to another. The ultimate impact of the shift to option trading is an open empirical question which we explore.

We focus our analysis on the dramatic fee reduction experienced by retail traders when Robinhood introduced free option trading in January 2018. Fees (on other platforms) that ranged between \$11 and \$28 an option on discount brokerages became zero. Not surprisingly, we find that the volume of single-contract options (a proxy for retail option trading) increased by more than a third around this time (Figure 1). We also find that volatility increased around this time and increased more so for stocks that saw a greater increase in retain option trading. Of course, these results on volatility are only suggestive since the drivers of volatility could also drive trading and even the volatility itself could drive trading. To establish causality we exam the impact of the fee reduction on two samples: stocks with shares cross-listed in the US and Canada, and dual class shares who have the same economic claims, but where one class has options and the other does not. Consistent with the overall results, in these two samples we find that the security for which options costs decreased sees an increase in volatility (relative to the relative to the equivalent optionless security).

We supplement the causal tests with cross-sectional tests where we condition on the degree to which we expect (*ex ante*) to see a greater impact from the fee reduction on option trading. This, once again, avoids concerns about causality. It also allows us to provide evidence on the possible mechanism at work linking the two markets. Our first measure exploits the relative attractiveness of using call options rather than buying the underlying stock. When the option is cheaper relative to the price, then a change in the fee would more likely tip a trader toward the option. Conversely, when the option is quite expensive, the fee would be irrelevant and a retail trader would not consider the option. Looking at the ratio of option prices to stock prices, we find that (as expected) retail trading of options is generally decreasing in this measure and (as conjectured) volatility is also declining. The magnitudes are striking. In the lowest quintile where options have a low relative price, the change in volatility is an increase of about 60%. In the highest quintile, the increase is about 14%.

Our second ex ante measure focuses on the underlying hedging mechanism we conjecture is at work. This is the omega for the average retail call option trade on a given stock, which measures the degree of embedded leverage. This measure is directly related to the market maker hedging activities that might link the markets. It may also reflect the desirability of option trading to retail traders who may be seeking leveraged positions. Either way, via hedging or demand, we conjecture that the volatility change is increasing in this ex ante measure. We find this to be the case and the magnitudes are striking: the lowest quintile of the measure sees a 12% increase in volatility after the fee reduction; the highest quintile see a 57% increase in volatility. These results are confirmed in regression analyses which include, among other controls, stock and date fixed effects. Given that we are suggesting a change in the very nature of volume in the underlying securities as a result of a level shift in retail trading in the options, the effects should not be observed only in very short-term measures of volatility. In effect, we are not arguing for a change in short-term price impact, but a structural shift in volatility. We find an increase in volatility when it is measured in 5-, 10-, 30-, and 60-minute intervals, or at a daily level for a week or a month.

To the extent a link exists between retail option trading and the underlying stocks, we may see other changes in market quality. In general, while the hedging activities will move stock prices, the fact that this volume reflects uninformed trades should benefit liquidity. We show that quoted spreads, effective spreads, realized spreads and price impacts all decline around the fee reduction. Similarly, and further corroborating our assumed mechanism, we see an increase in market making volumes and the volatility of market making activity.

We noted earlier that if trading in options substitutes for trading in the underlying securities, this shift could attenuate our results by reducing price pressure in the underlying. However, an interesting aspect of the hedging argument in Ni et al. (2021) is that a one-to-one shift in volume would still give rise to an increase in volatility in the underlying via the conjectured hedging mechanism. The reason is that gamma hedging requires a much larger position in the underlying stock than in the option due to the leverage implicit in the option. Thus, if our mechanism holds, a shift in retail volume may be generating the rise in volatility from otherwise identical retail trading demands. Of course, it is not clear that retail traders would not themselves make some adjustment to their trading demands to reflect leverage or, for other reasons, are not simply transferring the same dollar trading activity from one market to another. Whether it is a shift that is occuring or new option trading is being initiated, does not diminish the importance of recognising that in addition to concerns about options being appropriate for retail traders, we are documenting an additional implication for the quality of markets of underlying securities.

Taken together, our results suggest that the reduction in fees for option trading on Robinhood and the resulting increase in retail trading of options, generated an increase in the volatility of the underlying optioned securities. We conjecture, and provide supporting evidence, that this link is generated by market makers in the option markets hedging their net exposures in the underlying optioned securities.

The remainder of the paper is organized as follows. In Section 2, we describe the data and variables we use in our tests. Section 3 presents our main results, focusing on ex ante measures, and two difference-in-difference settings. In Section 4 we focus on the channels at plan and the market liquidity consequences of the increased idiosyncratic volatility. We investigate the complementary relation between retail trading in the option and stock market in Section 5. Section 6 concludes.

## Literature Review

Our work contributes the literature on the impact that retail trading has on stock market quality. Previous work showed that retail investors provide liquidity (Kaniel, Saar, and Titman, 2008; Barrot, Kaniel, and Sraer, 2016; Glossner, Matos, Ramelli, and Wagner, 2021; Ozik, Sadka, and Shen, 2021; Eaton et al., 2022b) and act as noise traders, which may increase (temporary) volatility (Brandt, Brav, Graham, and Kumar, 2010; Foucault, Sraer, and Thesmar, 2011). We contribute to this literature by showing that retail investors increase volatility on the stock market indirectly by trading in the option market. In fact, thanks to the leverage embedded in options, their choice to trade in the option rather than the underlying market may magnify the effect of retail trades on the volatility of the stock market.

Our work is closely related to a number of recent papers focused on retail trading of options.[3] Eaton, Green, Roseman, and Wu (2022a) show that signed option retail trading affect option prices and Hu, Kirilova, Park, and Ryu (2021) show that option retail investors lose to the rest of the market. Bryzgalova et al. (2023) show that option retail traders lose to arbitrageurs by sub-optimally exercising their options. They also note that this shift in retail trading benefits market makers who profit from very large spreads in options. Ernst and Spatt (2022) make a similar point regarding high spreads in the option market and note that payment for order flow is therefore more profitable. de Silva et al. (2022) observe that option retail trades cluster around earnings announcements that are expected to generate higher levels of volatility, driving up option prices to their disadvantage. As with the other papers cited above, they emphasize the high cost of option trading and, together with

[3]Earlier work on option retail trading, which mostly focused on their profitability and drivers, includes Lakonishok, Lee, Pearson, and Poteshman (2007); Lemmon and Ni (2008); Bauer et al. (2009); Choy and Wei (2012); Choy (2015); Dorn, Dorn, and Sengmueller (2015).

the price effect, how such trading disadvantages retail traders and benefits market makers. Whereas these papers emphasize option market characteristics and the resulting transfer of wealth away from retail traders, we focus on the impact of option trading, through the action of market maker hedging, on underlying securities.

Our work extends a line of research exploring whether option trading affects underlying security prices. Early work emphasized the impact of option trading around option expiration dates, when option trading volume would spike upwards. Klemkosky (1978), for example, document negative returns leading up to expiration dates and positive returns afterwards. Ni et al. (2021) find abnormal clustering of optioned securities prices around option strike prices. The studies suggest that underlying security liquidity is insufficient to fully absorb option-related trading activity, a necessary condition for the results we study. The impact of options on volatility has been a major focus of work given the relation between volatility and option prices.

It is well established that option order flow contains information and affects the price of the underlying (Ni, Pearson, and Poteshman, 2005; Roll, Schwartz, and Subrahmanyam, 2010; Hu, 2014; Ge, Lin, and Pearson, 2016; Chordia, Kurov, Muravyev, and Subrahmanyam, 2021; Weinbaum, Fodor, Muravyev, and Cremers, 2022). Results on the effect of options on volatility, however, have been mixed. Early work by Conrad (1989) suggests that the introduction of option trading reduces volatility, but Bollen (1998) provide evidence suggesting this is a result of the timing of option introductions. Most recently, Ni et al. (2021) show that market maker hedge rebalancing affects stock return volatility. As noted earlier, Eaton et al. (2022b) draw attention to the specific nature of retail trading that might impact volatility—it is the more naïve traders who are more likely to herd that lead directly to volatility in the markets at which they trade. We extend this literature in a number of directions. First, we provide additional evidence, and causal evidence by using optioned and optionless samples, of an impact of option trading on optioned security volatility. Second, we provide this evidence in the context of retail trading, which is unlikely to information motivated. And finally, we provide evidence linking this effect to the actions of market makers as they absorb retail trading volume.

Finally, a budding literature addresses the welfare implications of providing retail investors with leverage (Heimer and Simsek, 2019; Heimer and Imas, 2022) or with access to complex financial instruments (Knüpfer, Rantala, and Vokata, 2021; Vokata, 2021). We contribute to this literature by showing that lowering the barrier for unsophisticated investors to trade in derivatives not only impact those investors' profitability, but has negative externalities on the conditions of the broader financial markets.

## 2 Data

The main sample period of our study is from June 2017 to June 2018—i.e., six months before and after Robinhood's option introduction—and includes all ordinary shares of US-listed companies, and exchange traded funds (ETF), that are underly options. We exclude ADRs. In some analysis, we include optionless shares of US-incorporate companies and Canadian companies interliested in the US as control sample. Section 2.1 details the option data we employ, and Section 2.2 spells out the calculations of the measured used in the analyses.

### 2.1 Option Retail Trading

We obtain detailed option transactions data from the Chicago Board Options Exchange (CBOE). We observe all options transactions traded on US markets, as long as the contract trades also on CBOE. Thus, we observe all trades for options written on stocks and ETFs (but not indexes) that occurred on the 16 US option markets. We observe each trade's price, size, executing exchange, and NBBO quote, together with the underlying security's price.

We construct a measure of retail option trading by focusing on 1-contract transactions, the smallest available to traders, as fractional trades are not available for options. We calculate each trade's implied volatility, based on the trade characteristics and the price of the underlying at the time of trade.[4] We obtain contract-level end-of-day summary data from CBOE, which give us estimates for implied volatility and the greeks (we focus on Delta $\Delta = \frac{\partial o}{S}$, Gamma $\Gamma = \frac{\partial \Delta}{S}$, and Theta $\Theta = \frac{\partial o}{t}$) for each contract. To characterize the relative demand drivers for options over stocks, we calculate an option's omega, which captures its embedded leverage: $\Omega = \left| \frac{\partial o_t}{o_t} \left( \frac{\partial S_t}{S_t} \right)^{-1} \right| = \frac{|\Delta| S_t}{o_t}$, where $S_t$ is the underlying's price, and $o_t$ and $\Delta$ the option's price and delta, respectively (Frazzini and Pedersen, 2022).

Further, we obtain the Nasdaq Options Trade Outline (NOTO) and PHLX Options Trade Outline (PHOTO) which consists of trader type-by-trade size level data for trades that took place on the Nasdaq Options Market (NOM) or the Nasdaq PHLX (PHLX). This data details signed trading volume and changes in open interest for five types of traders and three trade sizes (up to 100, 100–199, more than 200). Traders are classified as firm proprietary traders, brokers and dealers, market makers, regular customers, or professional

[4]We use realized, forward-looking dividends to calculate a stock's dividend yield over the life of the option. We verify that the implied volatility we calculate is correct using the CBOE's own ex ante estimate and find that the two are almost indistinguishable.

customers. For each trader, day, and contract, the data reports the daily number of buy-to-open, buy-to-close, sell-to-open, and sell-to-close trades.

## 2.2 Other Data

We use the Trade and Quote (TAQ) data to qualify daily market conditions for the underlying securities, following Holden and Jacobsen (2014). We calculate trading volume, order imbalance, liquidity, and volatility measures. The time-$s$ relative quoted bid-ask spread is $QuotedSp_s = 100\frac{A_s - B_s}{M_s}$, where $A_s(B_s)$ is the national best ask (bid) price, and $M_s$ is the mid-quote. The relative effective spread, relative realized spread, and the price impact of trade-$k$ are calculated as $EffectiveSp_k = 100\frac{2D_k(P_k - M_s)}{M_s}$, $RealizedSp = 100\frac{2D_k(P_k - M_{s+5})}{M_s}$, and $PriceImpact = 100\frac{2D_k(M_{s+5} - M_s)}{M_s}$ where $D_k$ is an indicator variable that equals 1(-1) if the trade is buyer(seller)-initiated, following Lee and Ready, 1991, $P_k$ is the trade price, $M_s$ ($M_{s+5}$) is the midpoint at the time of (five minutes after) the trade. We dollar-volume-(time-)weigh trade and quote-based measures, respectively, for each stock-$i$ and day-$t$.

We calculate daily volatility measures for each stock-day using 5-, 10-, 30-, and 60-minute excess returns over the market, as proxied by returns of the SPY ETF. We calculate retail stock trading volume using the method by Boehmer, Jones, Zhang, and Zhang (2021): For each trade reported to FINRA (exchange code "D" in TAQ), we calculate the fraction of a penny $Z$ for transaction price $P$, $Z = 100 \mod (P, 0.01)$, and identify the trade as a retail buy (sell) if $0.6 < Z < 1$ ($0 < Z < 0.4$). We aggregate retail trading at the stock-day level.

We obtain stock characteristic from the Center for Research in Security Prices (CRSP). Trades and quotes data for the sample of Canadian stocks interlisted in the US are from the Toronto Stock Exchange (TSX), and include all nanosecond-stamped updates to the best bid- and ask-quotes. We obtain daily high- and low-values for the USD-CAD foreign exchange rate from Bloomberg, and use their difference to measure FX risk.

Whereas Figure 1 provides an overview of changes in options trading, emphasizing how fee reductions helped expand that trading, Figure 2 focuses on the dramatic change in trading that occurred after the Robinhood introduction of free option trading. The key here, which we exploit in our tests, is that we see a regime shift in trading. While the shift does take a bit over a month to be fully realized (a result of the slow roll out of the feature), the shift is economically striking and not a result of a continuing trend over our examination window.

# 3 Increase in Retail Trade and Volatility

In this section, we show that an increase in retail trading in the option market corresponded to higher idiosyncratic volatility of the underlying optioned securities. In Section 3.1, we establish the preliminary results based on an ex-post sorting of volume changes and also show that the change in underlying volatility we document is permanent. In Section 3.2, we obtain the same results when sorting stocks by the ex ante likelihood that a decrease in option trading costs will elicit higher retail trading. In Section 3.3 we examine a setting which plausibly demonstrates a causal increase in volatility from option trading: in a difference-in-difference analysis we compare the volatility changes of USD-denominated shares to CAD-denominated shares for cross-listed companies where only the USD-denominated shares are affected by option trading. We replicate this analysis in Section 3.4 for a set of companies with exchange-traded dual-share classes where some share classes have options and some do not.

## 3.1 Preliminary Result

We begin by showing that retail trading in the option market is related to a stock's idiosyncratic volatility for the full sample of US traded shares and ETFs. We estimate the following regression:

$$Volatility_{it} = \alpha_i + \alpha_t + \beta RetailOVolume_{it} + \varepsilon_{it} \tag{1}$$

where $Volatility_{it}$ is the logarithm of the standard deviation of the 5-minute returns net of the market returns for stock-$i$ on day-$t$, and $RetailOVolume_{it}$ is a measure of option retail trading, the logarithm of the 1-contract option trades for all options that have stock-$i$ on day-$t$ as the underlying security. $\alpha_i$ and $\alpha_t$ are stock- and day-fixed effects, and we cluster standard errors at the stock- and day-level.

We report the results in Table 1. An increase in retail trading in the option market is positively related to idiosyncratic volatility, and the relation is highly statistically significant. A 10% increase in option retail volume increases idiosyncratic volatility by 1%, alternatively, a 1-standard deviation increase in retail option volume increases volatility by 0.2 standard deviations. The result is not driven by total option volume ($OVolume_{it}$), as shown in Specification 2. In fact, an increase in *retail* volume impacts volatility more than a similar increase in *total* option volume. Since Foucault et al. (2011) show that retail trading in the stock market increases volatility, we control for the (log) retail and total trade volume in the stock market in Specification 4, which does not affect the statistical significance of the coefficients of interest. In Specification 5, we include industry-by-day fixed-effects, as retail investors tend to trade in a concentrated manner (Welch, 2022). Again we see that parameters are virtually unchanged.

Volatility and option market participation are clearly correlated. To achieve identification, we employ the introduction of option trading on the Robinhood platform, which drastically decrease trading cost for retail investors on the option market. In the next subsections, we argue for the causal relation between the two quantities of interest using a difference-in-difference setting, comparing relative volatility changes in inter-listed and dual-class shares. In this section, we focus on the sample of US-listed shares and show that ex-ante characteristics capturing a stock's propensity to be treated—that is, for which option trading volume should increase the most following a cut in trading costs—positively predict both increase in volatility and in retail option trading.

First, we show that the results hold ex-post. We identify stocks for which retail trading in the option market increased the most, based on the quantity of 1-contract trades in the three months before and after the Robinhood's introduction of option trading. Figure 3 shows that the scaled idiosyncratic volatility of stocks in the top tercile by option retail trading increase moves in parallel with the volatility of the stocks in the other two terciles, prior to the December 2017. After 2017, however, stocks that experienced a high increase in option retail trading also showed a more pronounced increase in idiosyncratic volatility.

Table 2 confirms the results from the figure in a difference-in-difference regression format:

$$Volatility_{it} = \alpha_i + \alpha_t + \beta IncreasedORT_i \cdot Post_t + \varepsilon_{it} \tag{2}$$

where $Volatility_{it}$ is regressed on $IncreasedORT_i$, a dummy that is one for stocks in the top tercile, and zero, otherwise, and $Post_t$, a dummy that is one after Robinhood option introduction and zero, otherwise. Specification 4 indicates that stocks for which option retail trading increased the most experience an increase in volatility 4% larger than the other stocks. Option retail trading for treated stocks increased by 52% more than for the latter (Specification 6). Figures 4 and 5 show the difference-in-difference parameters for Specification 5 and 6, respectively.

The effect we document is not simply an increase in high-frequency microstructural noise, as our results are robust to measuring volatility at much lower frequencies. In Table 3, we replicate Specification 3 of Table 2 for return volatility calculated at the 10-, 30-, and 60-minute frequency. We also replicate the analysis using weekly and monthly volatility, based on open-to-close returns. The increase in idiosyncratic volatility we document is remarkably stable in magnitude, regardless of the time frame used to calculate the dependent variable.

### 3.2 Sorting on Ex-ante Stock Characteristics

The results in Table 2 rely on ex post sorting. While the series display trends that are remarkably parallel, we cannot draw causal conclusions from this analysis. To be able to make a causal statement, we take two approaches: First we show that we obtain the same results when we sort stocks ex-ante along characteristics that would make retail investors sensitive to a fee change; second, we take a difference-in-difference approach, comparing assets affected by the Robinhood option introductions and assets that were not.

We hypothesize that, *ceteris paribus*, retail investors respond to the reduced cost of trading to a greater degree if the option price is low– that an \$11–28 decrease in trading cost is a more salient change for cheaper contracts than it is for expensive ones. To test this hypothesis, we sort stocks by their implied volatility, and verify that stocks with high implied volatility—i.e., stock that rank in the top-tercile by average implied volatility—experience both highest increase in volatility and retail option trading following the event.

Tests based on implied volatility, however, ignore that two options with identical moneyness and time-to-expiry differ in premium if the underlying security's prices differ. They also ignore that retail investor can lower option premiums by simply selecting deeper out-of-the-money options. We repeat the analysis and sort the stocks by the ratio of retail option trade prices (the average price for a 1-contract option trade) to underlying's stock price; we expect that stocks for which retail investors select cheaper options (compared to their underlying) will experience the largest increase in retail option trading and underlying volatility. Finally, we adjust the retail option-to-stock price ratio for the fact that investors may take into account the different leverage embedded in the options they select. Accordingly, we sort stocks by the average omega of the retail trades.

We estimate a regression similar to Eq. 2, where we substitute $IncreasedORT_i$ by $HighIV_i$, $HighO/S_i$, $HighOmega_i$, dummies that equal one if the stock rank in the top tercile for the corresponding measure in the three months prior to the Robinhood option introduction, and zero, otherwise:

$$Volatility_{it} = \alpha_i + \alpha_t + \beta HighIV_i \cdot Post_t + \varepsilon_{it} \tag{3}$$

We report the results in Table 4. The results show that stocks for which retail investors experienced a more salient decrease in options commissions experienced the largest increase in volatility and retail option volume. For example, stocks in the highest tercile of implied volatility experienced an increase in idiosyncratic volatility (option retail volume) 18% (11%) lower than stocks with lower implied volatility, in the six month surrounding Robinhood's option introduction. Similarly, stocks for which retail traders aimed at achieving the highest leverage using options experienced a 13% (9%) higher volatility (option retail trading) around the event.

### 3.3 Cross-listed Stocks

We address the concerns of endogeneity by comparing the US stock market to its Canadian counterpart. Figure 6 shows the average 5-minute volatility in Canada and the US around Robinhood's introduction of free option trading. The US stock market shows a significant increase in volatility already prior to the event we consider. However, we show next that at least some of the increase can be attributed to increased retail trading in the option market.

To argue that Robinhood's introduction of free option trading increased volatility, we turn to a set of 66 companies that list their shares on both Canadian and US stock markets. Contrary to American Depository Receipts, the shares traded in the US for these companies are economically the exact same claim on the company's cash flows, but they simply trade in different currencies. The Robinhood platform trades the USD-denominated shares and the options that have them as underlying. Robinhood, however, does not list foreign-exchange stocks. For example, it allows traders to buy USD-denominated shares of Precision Drilling Corporation (NYSE:PDS) and the CBOE options that have it as underlying. However, it does not allow investors to buy the company's CAD-denominated shares (TSX:PD) that are listed on the Toronto Stock Exchange nor the options that have them as underlying and trade on the Montreal Exchange.

To test whether the introduction of free option trading on Robinhood impacted shares idiosyncratic volatility, thus, we can compare the volatility of USD-denominated interlisted shares to the that of the corresponding CAD-denominated shares. Short of exchange rate volatility, any deviation between the two that takes place around the Robinhood event can be attributed to the increase in option retail trading.

Panel A of Figure 7 shows in red the relative difference in interlisted stock volatility. Prior to the event, the volatility difference is squarely centered around zero. Following the event, the volatility differential increases to up to 10%. We can interpret this measure as excess volatility in the US stock market. In that same panel, we report the volume of 1-contract trades traded in the US. The two series share a very remarkable commonality: The correlation between retail option trading intensity and US excess volatility is 43%, strongly supporting the hypothesis that an increase in the former led to the latter.

We can estimate the corresponding regression equation for the difference-in-difference setting,

$$Volatility_{it} = \alpha_i + \alpha_t + \beta US_i \cdot Post_t + \varepsilon_{it} \tag{4}$$

where $Volatility_{it}$ is the (log) 5-minute volatility of the USD- or CAD-denominated shares, $US_i$ is one for the former and zero for the latter, and $Post_t$ is one following December 2017, and zero, otherwise. We report the estimation results in Table 6. Specification 1 is estimate the entire sample of US and Canadian market: On average, Canadian stocks were 13% more volatile in the first six months of 2018 than their US counterparts. We estimate Specification 2 only for the sample of 66 interlisted companies, which shows that the USD-denominated shares were 7% more volatile following the introduction of options on Robinhood. Figure 8 reports the time series of the difference-in-difference parameters.

To rule out that foreign-exchange volatility explains a significant portion of the estimate, we regress the relative difference in volatility for the shares of interlisted companies, $Vol._{it}^{US} - Vol._{it}^{CA}$, on the $Post_t$ dummy and $FxVol_t$, the difference between the high and low CAD-USD rate for day-$t$:

$$Vol._{it}^{US} - Vol._{it}^{CA} = \alpha_i + \beta US_i \cdot Post_t + \gamma FxVol_t + \varepsilon_{it} \tag{5}$$

and report the results in Specification 3 of Table 6. The parameter of interest is only marginally smaller in magnitude, indicating that the volatility difference we observe is unrelated to FX considerations.

The arguments we made to support the differential effect of a decrese in retail trading cost along the line of option cost and embedded leverage should hold for the sample of interlisted canadian stocks, as well. We replicate the analysis in Eq. 4 and interact the term of interest with dummies capturing whether a USD-denominated stock of an interlisted company displayed high implied volatility, option-to-share price ratio, or omega in the three months prior to the event, and zero otherwise. We saturate the regression with stock-, time-by-treated, and stock-by-post-fixed effects, allowing us to focus on the triple diff-in-diff-in-diff parameters:

$$Volatility_{it} = \alpha_i + \alpha_i \cdot Post_t + \alpha_t + \alpha_t \cdot US_i + \beta US_i \cdot Post_t \cdot HighIV_i + \varepsilon_{it} \tag{6}$$

Table 7 reports the results. In this analysis, we compare the relative increase in relative volatility between USD- and CAD-denominated shares between two companies: A company with ex-ante cheap options experienced an increase in volatility 8.3% higher compared the the relative increase experienced by a company with expensive options.

### 3.4 Dual-class Shares

A peculiarity of the stock market allows us one more identification strategy. Thirteen companies in the US list two share classes on exchanges, yet only one share class per company acts as underlying for options.[5] This setting allows us to calculate a second measure of excess volatility: The differential between the standard deviation of 5-minute returns for the optioned and optionless share classes.

We report the average relative volatility difference for dual-class shares in Panel B of Figure 7, together with the volume of 1-contract trades traded in the US. Similarly to the interlisted sample, the commonality between this measure of excess volatility and the intensity of retail option trading is remarkable. We estimate the corresponding model

$$Volatility_{it} = \alpha_i + \alpha_t + \beta Optioned_i \cdot Post_t + \varepsilon_{it} \tag{7}$$

and report the result in Specification 1 of Table 8, which indicates that the post-event volatility is 13% higher for optioned vis-a-vis optionless shares.

## 4 Channels and Consequences

In this section, we provide support for the channel at play, arguing that the higher volatility follows from the stronger and more uncertain hedging demand by the option market makers. Section 4.2 shows that the liquidity of affected stocks increased, consistent with the option order flow being uninformed.

### 4.1 Market Making Intensity

Through which channel does increase in trading in the option market affect the stock market? We hypothesize that the hedging actions of market makers play a significant role,

[5] Liberty Global lists three share classes, with two of them acting as underlying for options.

in line with Ni et al. (2021): A larger option demand from retail investor translates into larger inventories, which lead to increased volatility thanks to the market maker's hedging activities.

We estimate the intensity of market maker hedging demand by calculating daily increases in their option inventory. Using the PHOTO/NOTO datasets, we calculate the total amount of options purchases (sells) intermediated by the market maker, for all stock-$i$ contracts on day-$t$, $MMBuyVol_{it}$ ($MMSellVol_{it}$). To estimate the *net* increase coming from retail investors, we calculate the absolute order imbalance coming from 1-contract trades, $|RetCallBuy - RetCallSell|_{it}$. We replicate the difference-in-difference analysis of Eq. 2 and 3 with the three inventory increasing measures and report the results in Tables 9 and 10.

The results are consistent with a hedging-demand story: Stocks for which retail investing in options increased the most, exhibit the highest increases in the inventory held by market makers, both in gross and net terms. These stocks, in turn, exhibit the highest increase in volatility. The results hold both from an ex-post perspective, and from an ex-ante: For example, stocks with lower option prices exhibit the highest increase in market maker inventory, consistent with option-trading commissions being most significant for investors trading in those assets.

Our current lack of option trading data for the Canadian market does not allow us to verify that the results hold in the interlisted sample, while the dual-class sample does not lend itself to replicating this analysis, given that one of the classes is optionless.

### 4.2 Effect on Liquidity

If the higher idiosyncratic volatility experienced by some stocks reflects an increase in noise trading—amplified by the leverage granted to retail investors by options—the model by Kyle (1985) suggests that those stocks should also experience an increase in market liquidity, as informed traders can more successfully trade without moving prices.

We test this conjecture, and replicate Eq. 2 using liquidity measures as dependent variables, and report the results in Table 11. We find that, indeed, stocks that experienced an increase in retail trading in the option market become *more liquid* in the stock market, despite an increase in their idiosyncratic volatility: Stocks in the top-tercile for increase in retail option trading exhibit a quoted (effective) bid-ask spread 1.8% (0.8%) smaller. Results are similar for the realized spread and related price impact. The difference-in-difference parameters for $QuotedSp_{it}$ are shown in Figure 9.

We replicate the analysis for the setting of dual-class shares, and show the results in Specifications 2–5 in Table 8. In this more credibly identified setting, we can show that liquidity for optionless share classes, which could not be affected by Robinhood's introduction of options, decreased compared to share classes with option traded on them, despite experiencing lower volatility. The relative bid-ask spread for optionless share classes increases 13% compared to their counterparts.

## 5 Complementarity between the Stock and Option Market

We have shown that retail investors' increased involvement in the option market increased stocks' idiosyncratic volatility, while improving their liquidity. It is not clear whether the improved accessibility of the option market made it a closer substitute or a complement to the stock market.

We calculate the cross-sectional rank-correlation between the fraction of volume coming from retail traders in the option (using the 1-contract trade measure) and stock market (using the BJZZ algorithm), and report it in Figure 10. We observe a significant increase in the correlation following Robinhood's option trading introduction. We interpret this result as suggesting that retail investors increasingly considered the option market as a substitute for their stock investing, as their cost of doing so decreased.

## 6 Conclusions

The advent of low-fee trading in options is likely to affect retail trader welfare and this has been explored in a number of papers. We identify another important outcome and provide evidence of its scale and existence: that increases in retail option trading may lead to increased volatility in the underlying optioned securities. The mechanism linking retail option trading activity to the underlying securities, we conjecture, is option market makers hedging their positions.

Clearly any effect of option trading will be predicated on there being a resulting change in option activity. We show, not surprisingly, the the introduction of free option trading on

Robinhood did, in fact, raise option trading. The impact on individual stocks may vary substantially in the cross section and we make use of that variation to assess the impact of the Robinhood change. In particular, we show the increase in volatility is larger for stocks were ex post and ex ante we expect a larger change in option trading. We supplement that analysis with two settings which we believe establish causality - a comparison around the Robinhood event of otherwise identical stocks where one set has options and the other does not: stocks listed in the US (options) and Canada (no options) and dual class shares where one class has options and the other does not. We also provide some evidence to support our conjectured channel. In particular, that the increase in volatility is greater for stocks where there is a great buy/sell imbalance and higher market maker inventories.

All told, our results suggest a statistically and economically significant increase in volatility of underlying stocks where retail option volume is increased. This work offers a new focus for the debate on retail option trading: not only should trader welfare be considered, but also market quality for the underlying securities.

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# Figures

### Figure 1. Predominance of Retail Trades in the Option Market

These figure shows the time-series evolution of 1-contract trades volume in absolute amounts and as a fraction of total option volume.

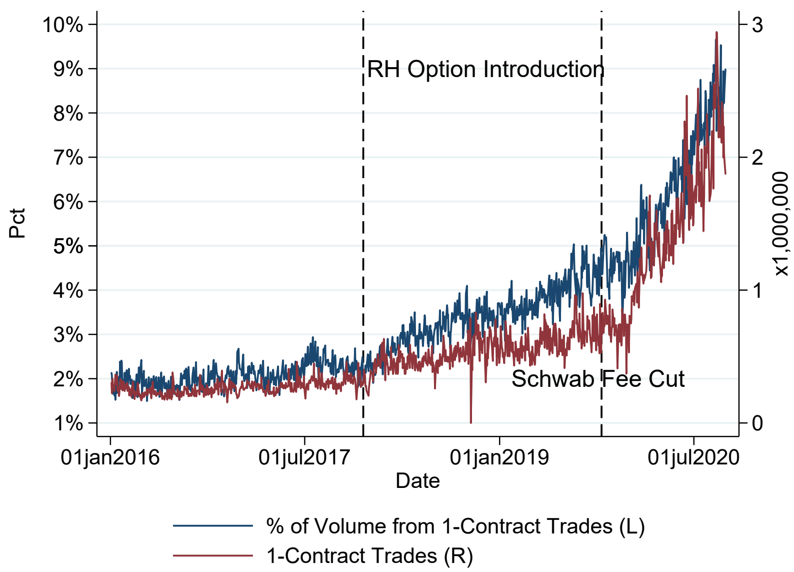


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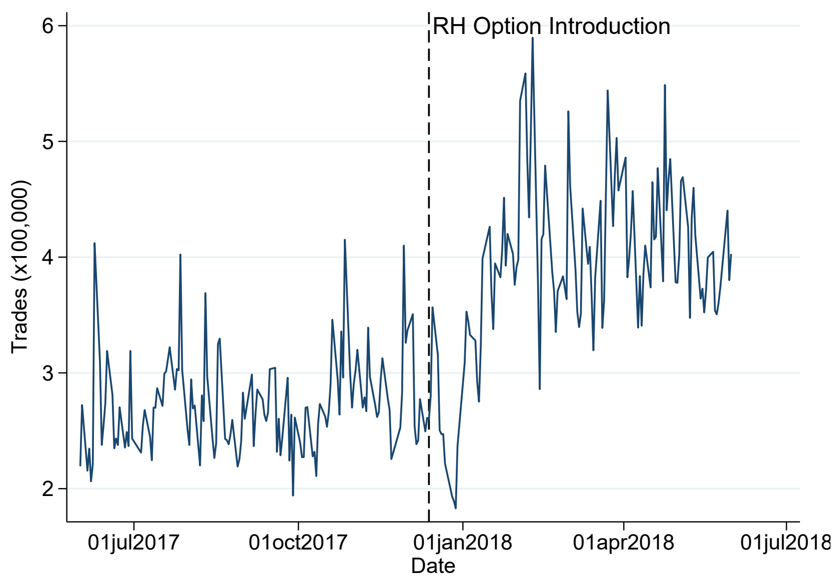
**Figure 2. Increase in Option Retail Trading Around Robinhood Free Option Introduction**

This figure shows the time series evolution of option retail trading around the introduction of free option trading on Robinhood. Option retail trading is measured as number of 1-contract trades, in hundreds of thousands of trades.



## Figure 3. Stock Volatility and Option Retail Trading

This figure shows the stock market volatility for two groups of companies, based on whether they experienced a large or small increase in retail option trading around the introduction of free option trading on Robinhood. We standardize the volatility of the two groups by dividing it by its value at the beginning of the sample.

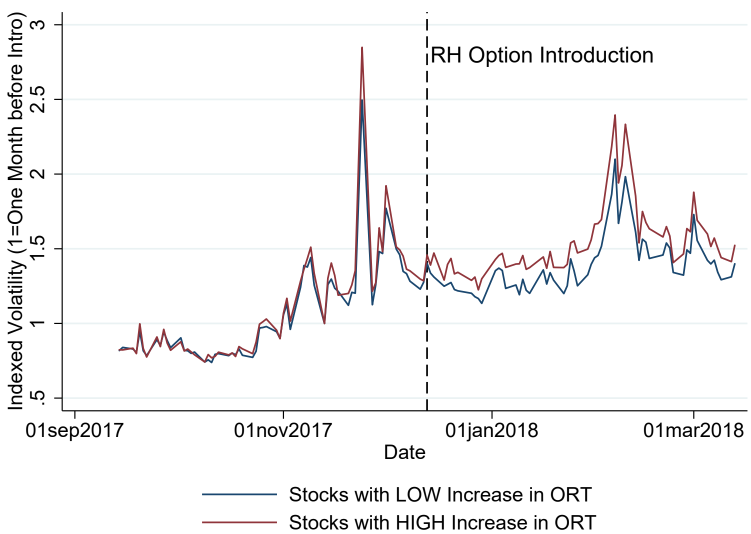
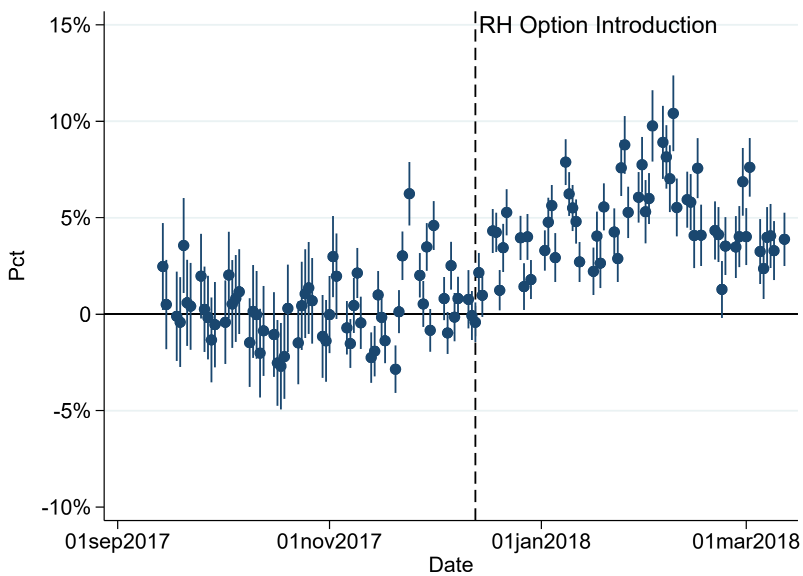


**Figure 4. Stock Volatility and Option Retail Trading**

This figure shows the relative difference in volatility for two groups of stocks, based on whether they experienced a large or small increase in retail option trading around the introduction of free option trading on Robinhood. We estimate a diff-in-diff model, where the change in retail trading is the treatment and the post-period follows the change in RobinHood option trading fee.



### Figure 5. Fee Changes and Option Retail Trading

This figure shows the relative difference in 1-contract share volume for two groups of stocks, based on whether they experienced a large or small increase in retail option trading around the introduction of free option trading on Robinhood. We estimate a diff-in-diff model, where the change in retail trading is the treatment and the post-period follows the introduction of free option trading on Robinhood.

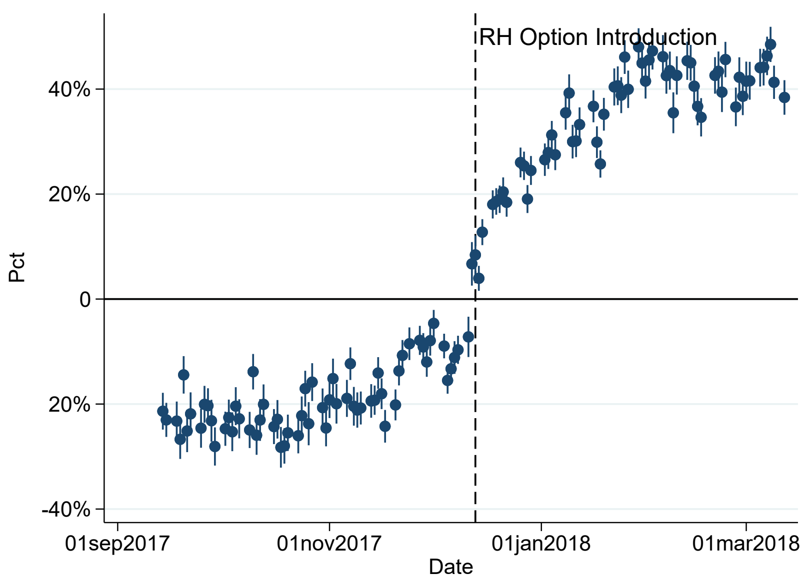
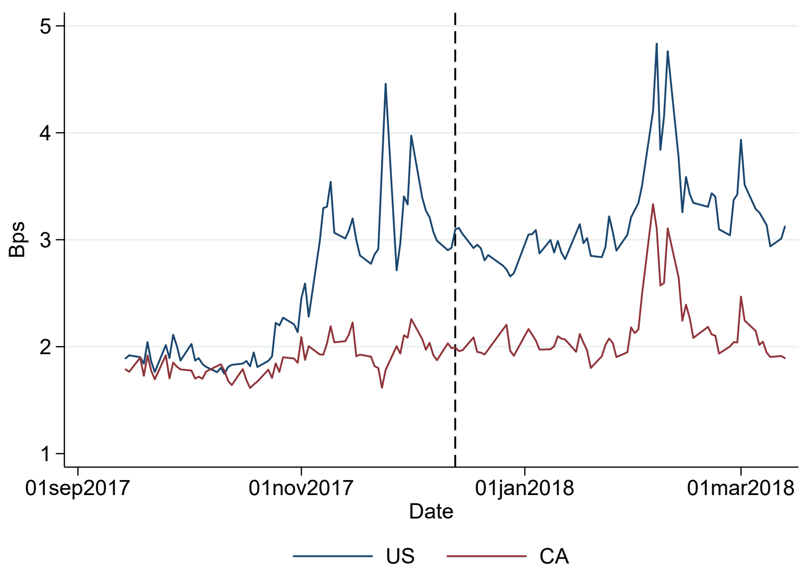


**Figure 6. Stock Market Volatility: The US and Canada**

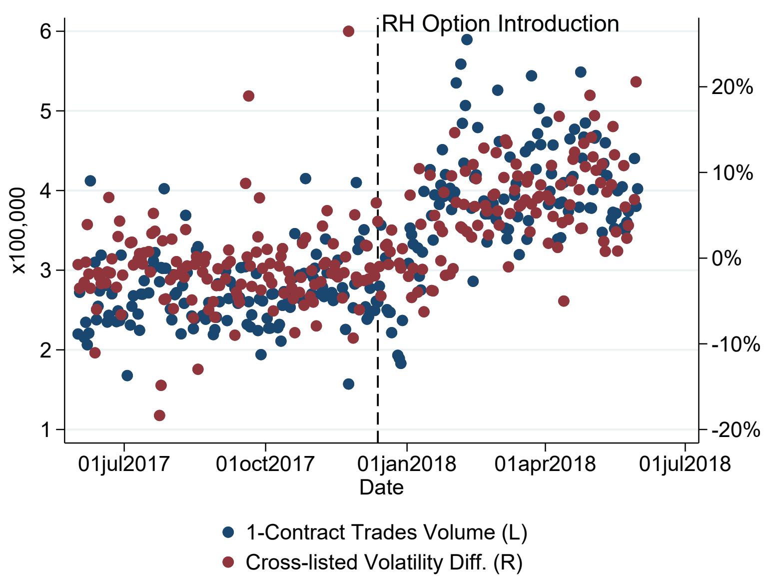
This figure shows the time-series variation of the average 5-minute volatility for the US and Canadian stock market.



## Figure 7. Option Retail Trading and Excess Volatility

This figure shows the daily number of 1-contract option trades on CBOE (left $y$-axis), together with an estimate of excess volatility (right $y$-axis). The excess volatility is estimated as the average relative difference between the volatility of the US and Canadian shares of interlisted companies, in Panel A, and as the average relative difference between the volatility of two share classes, for a set of US companies for which both share classes are traded on the stock market, yet only one share class is the underlying of options. The vertical line marks the change in RobinHood option trading fee.

A: Interlisted Counterfactual




B: Dual Class Counterfactual

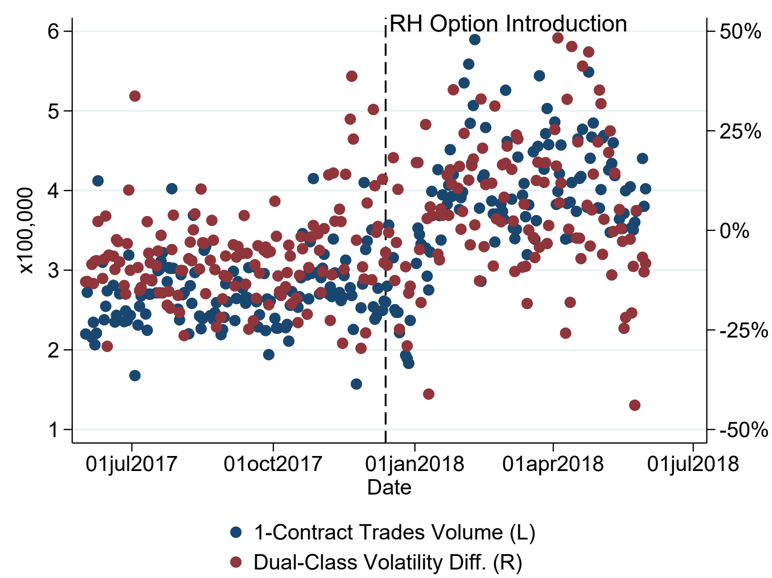


**Figure 8. Increase in Volatility: Interlisted Canadian Stocks**

This figure shows the the diff-in-diff parameters for the specification in Eq. 4, and represents the relative difference in 5-minutes volatility between interlisted canadian stocks and their US counterpart. We estimate a diff-in-diff model, where the treated share is that traded in the US market, the control is its Canadian counterpart, and the post-period follows the introduction of free option trading on Robinhood.

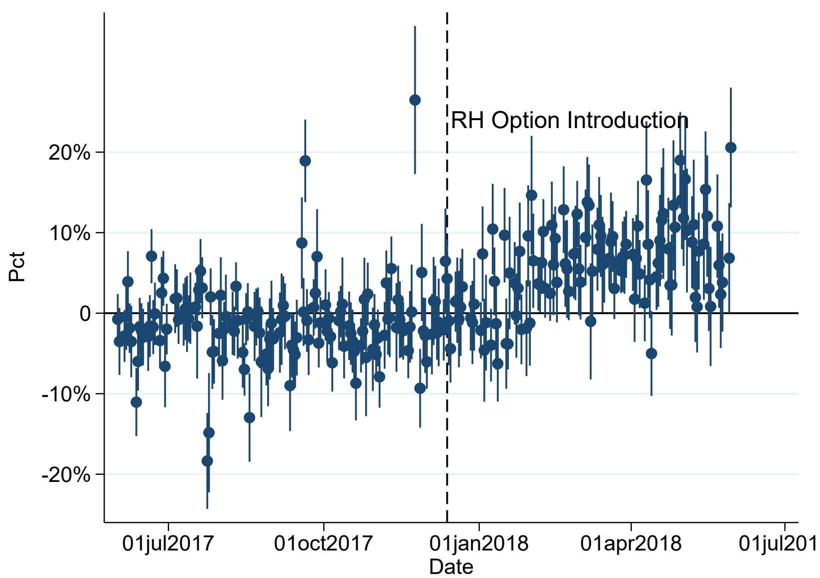


**Figure 9. Stock Liquidity and Option Retail Tradin**

This figure shows the relative difference in relative bid-ask spread for two groups of stocks, based on whether they experienced a large or small increase in retail option trading around the RobinHood fee change. We estimate a diff-in-diff model, where the change in retail trading is the treatment and the post-period follows the change in RobinHood option trading fee.

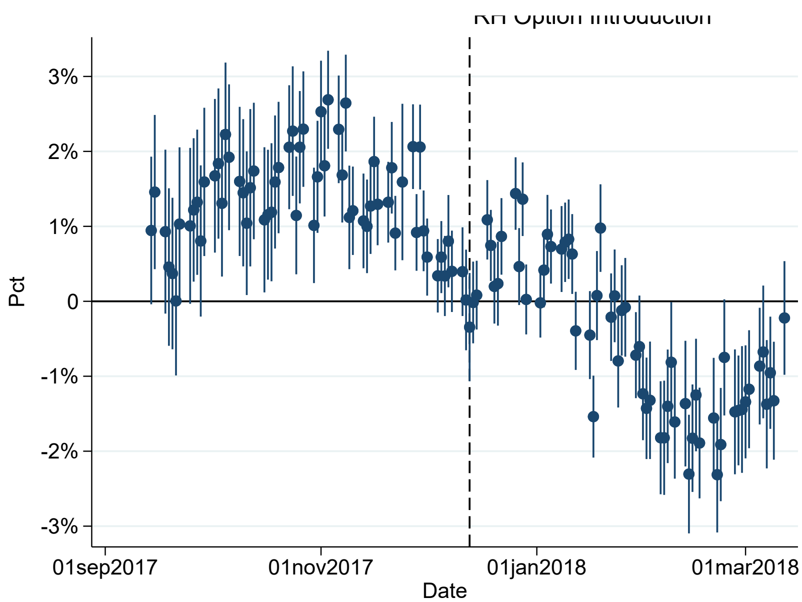
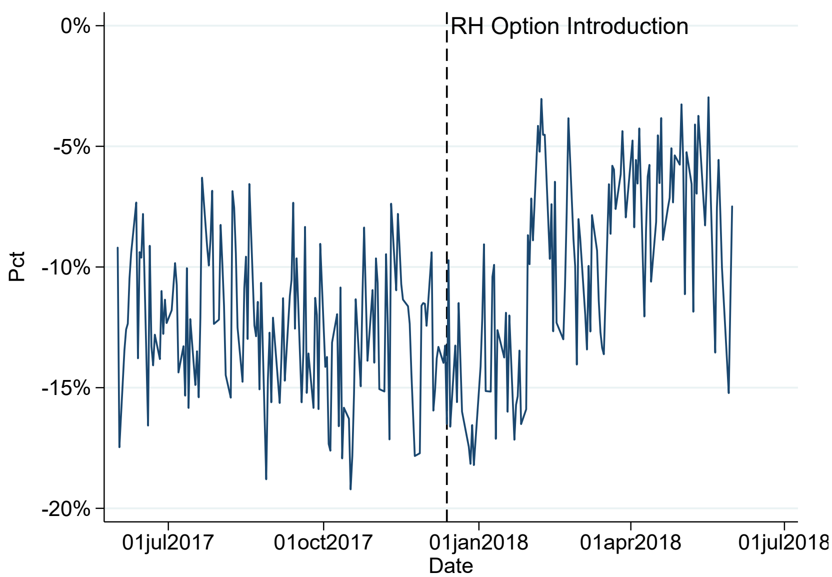


**Figure 10. Cross-sectional Correlation between Retail Investing in the Stock and Option Market**

This figure shows the cross-sectional rank-correlation between measures of retail trading in the stock and option market. The measure for the stock (option) market is calculated as ratio of trading volume coming from 1-contract trades (trades identified as retail by the BJZZ algorithm).



# Tables

**Table 1**
**Volatility and Retail Option Trading**

This table shows the relation between the (log) 5-minute volatility of the stock price, $Volatility_{it}$, and the quantity of one-contract trades on the option market, $RetailOVolume_{it}$. We control for the stock's relative bid-ask spread, $QuotedSp_{it}$, and the traded volume on the stock, $SVolume_{it}$, and option market, $OVolume_{it}$. We include stock-, date-, and date-industry-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| | (1)<br>$Volatility_{it}$ | (2)<br>$Volatility_{it}$ | (3)<br>$Volatility_{it}$ | (4)<br>$Volatility_{it}$ | (5)<br>$Volatility_{it}$ |
|---|---|---|---|---|---|
| $RetailOVolume_{it}$ | 0.090$^{***}$ | 0.069$^{***}$ | | 0.025$^{***}$ | 0.022$^{***}$ |
| | (28.920) | (27.686) | | (13.540) | (11.651) |
| $OVolume_{it}$ | | 0.031$^{***}$ | 0.062$^{***}$ | 0.011$^{***}$ | 0.011$^{***}$ |
| | | (25.528) | (29.722) | (11.970) | (11.400) |
| $RetailOVolume_{it}/OVolume_{it}$ | | | 0.168$^{***}$ | | |
| | | | (24.855) | | |
| $RetailSVolume_{it}$ | | | | 0.062$^{***}$ | 0.064$^{***}$ |
| | | | | (17.953) | (18.315) |
| $SVolume_{it}$ | | | | 0.171$^{***}$ | 0.158$^{***}$ |
| | | | | (16.537) | (17.118) |
| $QuotedSp_{it}$ | | | | 0.950$^{***}$ | 0.943$^{***}$ |
| | | | | (5.183) | (5.644) |
| Stock FE | Yes | Yes | Yes | Yes | Yes |
| Date FE | Yes | Yes | Yes | Yes | Yes |
| Date-Industry FE | No | No | No | No | Yes |
| Adj. $R^2$ | 0.750 | 0.752 | 0.750 | 0.786 | 0.805 |
| Obs | 294,769 | 294,769 | 294,769 | 292,562 | 263,456 |

## Table 2
## Volatility and Retail Option Trading around RobinHood Option Trading Fee Cut

This table shows how the (log) 5-minute volatility of the stock price, $Volatility_{it}$, changed around RobinHood's introduction of free option trading. We control for the stock's relative bid-ask spread, $QuotedSp_{it}$, and the traded volume on the stock, $SVolume_{it}$. $IncreasedORT_i$ is a dummy equal to one for the stock that experience a large increase in retail-option trading when RobinHood decreased fees on option trading and zero, otherwise. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock-, date-, and date-industry-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| | (1)<br>$Volatility_{it}$ | (2)<br>$Volatility_{it}$ | (3)<br>$Volatility_{it}$ | (4)<br>$Volatility_{it}$ | (5)<br>$Volatility_{it}$ | (6)<br>$Volatility_{it}$ | (7)<br>$RetailOVolume_{it}$ | (8)<br>$RetailOVolume_{it}$ |
|---|---|---|---|---|---|---|---|---|
| $IncreasedORT_i$=1 × $Post_t$=1 | | 0.033*** | 0.045*** | 0.044*** | 0.053*** | 0.038*** | | 0.520*** |
| | | (3.840) | (4.582) | (4.466) | (5.577) | (4.062) | | (24.538) |
| $Post_t$=1 | 0.293*** | 0.284*** | 0.270*** | | | | 0.092*** | |
| | (7.901) | (7.694) | (7.329) | | | | (5.212) | |
| $IncreasedORT_i$=1 | | −0.226*** | | | | | | |
| | | (−7.293) | | | | | | |
| $QuotedSp_{it}$ | | | | | 0.599*** | 0.596*** | | −0.222*** |
| | | | | | (12.871) | (13.932) | | (−3.060) |
| $SVolume_{it}$ | | | | | 0.079 | 0.049 | | 0.176 |
| | | | | | (1.222) | (0.992) | | (1.541) |
| Stock FE | No | No | Yes | Yes | Yes | Yes | No | Yes |
| Date FE | No | No | No | Yes | Yes | Yes | No | Yes |
| Date-Ind. FE | No | No | No | No | No | Yes | No | Yes |
| Adj. $R^2$ | 0.024 | 0.034 | 0.721 | 0.768 | 0.782 | 0.795 | 0.001 | 0.859 |
| Obs | 432,346 | 432,346 | 432,346 | 432,346 | 432,133 | 401,074 | 294,786 | 265,668 |

## Table 3
## Trading Fee Reduction on Volatility of Varying Tenor

This table shows how the volatility of the stock price changed around RobinHood's introduction of free option trading. We measure the daily volatility using 5-, 10-, 30-, and 60-minute returns. We measure weekly (monthly) volatility, $1WeekDayVol_{it}$ ($1MoDayVol_{it}$), using open-to-close daily returns. $IncreasedORT_i$ is a dummy equal to one for the stock that experience a large increase in retail-option trading when RobinHood decreased fees on option trading and zero, otherwise. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock- and date-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| | (1) $5MinVol_{it}$ | (2) $10MinVol_{it}$ | (3) $30MinVol_{it}$ | (4) $60MinVol_{it}$ | (5) $1WeekDayVol_{it}$ | (6) $1MoDayVol_{it}$ |
|---|---|---|---|---|---|---|
| $IncreasedORT_i$=1 × $Post_t$=1 | 0.044$^{***}$ | 0.049$^{***}$ | 0.055$^{***}$ | 0.057$^{***}$ | 0.131$^{***}$ | 0.165$^{***}$ |
| | (4.466) | (5.753) | (7.327) | (7.805) | (6.707) | (6.031) |
| Stock FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.768 | 0.764 | 0.737 | 0.688 | 0.629 | 0.799 |
| Obs | 432,346 | 432,343 | 432,336 | 432,329 | 94,154 | 24,461 |

**Table 4**
**Determinants of Increased Volatility and Retail Option Trading around RobinHood Cost Reduction**

This table shows how the (log) 5-minute volatility of the stock price, $Volatility_{it}$ in Panel A, and volume of 1-contract option trades, $RetailOVolume_{it}$ in Panel B, changed around RobinHood's introduction of free option trading. $HighS$ is a dummy equal to one if the stocks ranked in the top tercile of stock price in the three months prior to the cost reduction and zero, otherwise. $HighIV_t$ is one if the volume-weighted average implied volatility for options written on stock-$t$ is in the top tercile, and zero, otherwise. $HighO/S_{it}$ similarly is one for shares with a high ratio of 1-contract option trades prices and stock prices, and zero, otherwise. $HighOmega_{it}$ is one for shares ranking in the top tercile for option-embedded leverage ($\frac{\Delta \cdot S}{O}$) and zero, otherwise. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock- and date-fixed effects. *, **, and *** indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| Panel A: $Volatility_{it}$ | | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $HighS_i$=1 × $Post_t$=1 | 0.179*** | | | |
| | (10.289) | | | |
| $HighIV_i$=1 × $Post_t$=1 | | −0.177*** | | |
| | | (−10.692) | | |
| $HighO/S_i$=1 × $Post_t$=1 | | | −0.162*** | |
| | | | (−10.756) | |
| $HighOmega_i$=1 × $Post_t$=1 | | | | 0.132*** |
| | | | | (9.488) |
| Stock FE | Yes | Yes | Yes | Yes |
| Date FE | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.770 | 0.770 | 0.770 | 0.769 |
| Obs | 432,346 | 432,346 | 432,346 | 432,346 |

| Panel B: $RetailOVolume_{it}$ | | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $HighS_i$=1 × $Post_t$=1 | 0.054*** | | | |
| | (2.661) | | | |
| $HighIV_i$=1 × $Post_t$=1 | | −0.106*** | | |
| | | (−4.643) | | |
| $HighO/S_i$=1 × $Post_t$=1 | | | −0.097*** | |
| | | | (−4.249) | |
| $HighOmega_i$=1 × $Post_t$=1 | | | | 0.089*** |
| | | | | (4.469) |
| Stock FE | Yes | Yes | Yes | Yes |
| Date FE | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.847 | 0.847 | 0.847 | 0.847 |
| Obs | 294,769 | 294,769 | 294,769 | 294,769 |

**Table 5**
## Determinants of Increased Volatility and Retail Option Trading around RobinHood Cost Reduction

This table shows the increase in 5-minute stock price volatility, $Volatility_{it}$, and volume of 1-contract option trades, $RetailOVolume_{it}$, around RobinHood's introduction of free option trading. We calculate the change in the two variables between 90 days before and after the event, for each stock. In Panel A, we report the median change by the pre-event rank of the ratio of 1-contract option trades prices and stock prices, $O/S_{it}$, and option-embedded leverage, $\frac{\Delta \cdot S}{O}$. In Panel B and C, we repeat the same exercise, but sort the stock by the pre-event ranks of two variables, the stocks price, $S_i$, and the volume-weighted average implied volatility for options written on stock-$t$, $HighIV_t$. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

Panel A: One-way sorts

| | by $O/S_i$ | | by $\frac{\Delta \cdot S}{O}$ | |
|---|---|---|---|---|
| Rank | $Volatility_{it}$ | $RetailOVolume_{it}$ | $Volatility_{it}$ | $RetailOVolume_{it}$ |
| 0 | 0.601 | 0.267 | 0.117 | 0.021 |
| 1 | 0.486 | 0.222 | 0.296 | 0.098 |
| 2 | 0.375 | 0.097 | 0.390 | 0.129 |
| 3 | 0.275 | 0.111 | 0.492 | 0.239 |
| 4 | 0.124 | 0.000 | 0.596 | 0.267 |

Panel B: Two-way sorts, by $IV_i$ (down) and $S_i$ (across)
$Volatility_{it}$

| | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | −0.652 | 0.294 | 0.620 | 0.705 | 0.775 |
| 1 | 0.056 | 0.238 | 0.387 | 0.577 | 0.536 |
| 2 | 0.270 | 0.262 | 0.340 | 0.489 | 0.446 |
| 3 | 0.105 | 0.209 | 0.315 | 0.417 | 0.336 |
| 4 | 0.074 | 0.191 | 0.224 | 0.211 | 0.192 |

Panel C: Two-way sorts, by $IV_i$ (down) and $S_i$ (across)
$RetailOVolume_{it}$

| | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 1.048 | 0.165 | 0.333 | 0.355 | 0.400 |
| 1 | 1.000 | 0.198 | 0.282 | 0.221 | 0.204 |
| 2 | 0.524 | 0.084 | 0.133 | 0.027 | 0.102 |
| 3 | 0.053 | 0.078 | 0.096 | −0.009 | 0.041 |
| 4 | 0.012 | 0.071 | 0.134 | 0.011 | −0.028 |

**Table 6**
## Trading Fee Reduction and Stock Market Volatility: Interlisted Companies

This table shows how the (log) 5-minute volatility of the stock price, $Volatility_{it}$, changed around RobinHood's introduction of free option trading. We estimate a diff-in-diff model on a sample of 66 Canadian companies who list their shares on both the Toronto and NASDAQ/NYSE stock exchange. $Treated_i$ is a dummy equal to one for the USD-denominated share, and zero, for the CAD-denominated share. $Vol_{it}^{US} - Vol_{it}^{CA}$ is the log-difference between the volatility of shares of the same companies that are denominated in different currencies. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock- and date-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level.

| | (1)<br>$Volatility_{it}$ | (2)<br>$Volatility_{it}$ | (3)<br>$Vol._{it}^{US} - Vol._{it}^{CA}$ |
|---|---|---|---|
| $Treated_i$=1 × $Post_t$=1 | 0.134$^{***}$ | 0.069$^{***}$ | |
| | (4.785) | (2.745) | |
| $Post_t$=1 | | | 0.065$^{***}$ |
| | | | (4.066) |
| $FxVol_t$ | | | 2.102$^{*}$ |
| | | | (1.940) |
| Stock FE | Yes | Yes | Yes |
| Time FE | Yes | Yes | No |
| Adj. $R^2$ | 0.704 | 0.761 | 0.119 |
| Obs | 543,795 | 30,620 | 15,307 |

## Table 7
## Trading Fee Reduction and Stock Market Volatility: Interlisted Companies

This table shows how the (log) 5-minute volatility of the stock price, $Volatility_{it}$, changed around RobinHood's introduction of free option trading. We estimate a diff-in-diff-in-diff model on a sample of 66 Canadian companies who list their shares on both the Toronto and NASDAQ/NYSE stock exchange. $HighS$ is a dummy equal to one if the (USD-denominated) stock ranked in the top tercile of stock price in the three months prior to the cost reduction and zero, otherwise. $HighIV_t$ is one if the volume-weighted average implied volatility for options written on stock-$t$ is in the top tercile, and zero, otherwise. $HighO/S_{it}$ similarly is one for shares with a high ratio of 1-contract option trades prices and stock prices, and zero, otherwise. $HighOmega_{it}$ is one for shares ranking in the top tercile for option-embedded leverage ($\frac{\Delta \cdot S}{O}$) and zero, otherwise. $Treated_i$ is a dummy equal to one for the USD-denominated share, and zero, for the CAD-denominated share. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock, stock-period, and treated status–period fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level.

| | (1)<br>$Volatility_{it}$ | (2)<br>$Volatility_{it}$ | (3)<br>$Volatility_{it}$ | (4)<br>$Volatility_{it}$ |
|---|---|---|---|---|
| $Treated_i$=1 × $Post_t$=1 × $HighS_i$=1 | 0.135$^{***}$ | | | |
| | (6.539) | | | |
| $Treated_i$=1 × $Post_t$=1 × $HighIV_i$=1 | | −0.083$^{***}$ | | |
| | | (−5.869) | | |
| $Treated_i$=1 × $Post_t$=1 × $HighO/S_i$=1 | | | −0.103$^{***}$ | |
| | | | (−9.025) | |
| $Treated_i$=1 × $Post_t$=1 × $HighOmega_i$=1 | | | | 0.048$^{**}$ |
| | | | | (2.041) |
| Stock FE | Yes | Yes | Yes | Yes |
| Time-Treated FE | Yes | Yes | Yes | Yes |
| Stock-Post FE | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.773 | 0.773 | 0.773 | 0.773 |
| Obs | 30,620 | 30,620 | 30,620 | 30,620 |

**Table 8**
**Trading Fee Reduction and Stock Market Volatility and Liquidity: Dual-Class Shares**

This table shows how the (log) 5-minute volatility of the stock price, $Volatility_{it}$, and liquidity measures changed around RobinHood's introduction of free option trading. We estimate a diff-in-diff model on a sample of 13 US companies who list more than one share class on the stock exchanged, and for which at least one class is the underlying of option contracts. $Treated_i$ is a dummy equal to one for the classes underlying option contracts, and zero, otherwise. $QuotedSp_{it}$ ($EffectiveSp_{it}$) [$RealizedSp_{it}$] is the relative quoted (effective) [realized] bid-ask spread. $PriceImpact_{it}$ is the five-minute measure of price impact. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include share-class- and date-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level.

| | (1) $Volatility_{it}$ | (2) $QuotedSp_{it}$ | (3) $EffectiveSp_{it}$ | (4) $RealizedSp_{it}$ | (5) $PriceImpact_{it}$ |
|---|---|---|---|---|---|
| $Treated_i$=1 × $Post_t$=1 | 0.134$^{***}$ | −0.134$^{***}$ | −0.120$^{***}$ | −0.071$^{***}$ | −0.028$^{**}$ |
| | (7.155) | (−5.282) | (−4.976) | (−2.965) | (−2.259) |
| Stock FE | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.399 | 0.739 | 0.661 | 0.566 | 0.236 |
| Obs | 6,380 | 6,380 | 5,841 | 5,839 | 5,839 |

## Table 9
## Trading Fee Reduction and Option Market Making

This table shows how measures of option market making changed around RobinHood's introduction of free option trading. $MMBuyVol_{it}$ ($MMSellVol_{it}$) is the total number of option contracts bought (sold) by dealers, in their market-making capacity, for options written on stock-$i$ on day-$t$. $|RetCallBuy - RetCallSell_{it}|$ is absolute signed volume trading by retail investors in call options. $ImplVol_{it}$ is the volume weighted average implied volatility for options written on stock-$i$ on day-$t$. $IncreasedORT_i$ is a dummy equal to one for the stock that experience a large increase in retail-option trading when RobinHood decreased fees on option trading and zero, otherwise. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock- and date-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| | (1)<br>$\|RetCallBuy - RetCallSell\|_{it}$ | (2)<br>$\|RetCallBuy - RetCallSell\|_{it}$ | (3)<br>$MMBuyVol_{it}$ | (4)<br>$MMSellVol_{it}$ | (5)<br>$ImplVol_{it}$ |
|---|---|---|---|---|---|
| $IncreasedORT_i$=1 × $Post_t$=1 | | 2.042$^{***}$ | 50.111$^{***}$ | 52.882$^{***}$ | 0.021$^{***}$ |
| | | (13.105) | (6.611) | (7.010) | (7.506) |
| $Post_t$=1 | 0.584$^{***}$ | | | | |
| | (6.027) | | | | |
| Stock FE | No | Yes | Yes | Yes | Yes |
| Date FE | No | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.001 | 0.580 | 0.831 | 0.816 | 0.847 |
| Obs | 294,786 | 294,769 | 231,845 | 231,845 | 291,736 |

## Table 10
## Trading Fee Reduction and Option Market Making

This table shows how measures of option market making, changed around RobinHood's introduction of free option trading. Panel A shows the change in $MMBuyVol_{it}$, the total number of option contracts bought by dealers, in their market-making capacity, for options written on stock-$i$ on day-$t$. Panel B shows the effect on $|RetCallBuy - RetCallSell_{it}|$, the absolute signed volume trading by retail investors in call options. $HighS$ is a dummy equal to one if the stocks ranked in the top tercile of stock price in the three months prior to the cost reduction and zero, otherwise. $HighIV_t$ is one if the volume-weighted average implied volatility for options written on stock-$t$ is in the top tercile, and zero, otherwise. $HighO/S_{it}$ similarly is one for shares with a high ratio of 1-contract option trades prices and stock prices, and zero, otherwise. $HighOmega_{it}$ is one for shares ranking in the top tercile for option-embedded leverage ($\frac{\Delta \cdot S}{O}$) and zero, otherwise. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock- and date-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| Panel A: $MMBuyVol_{it}$ | | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $HighS_i$=1 × $Post_t$=1 | 28.158$^{***}$ | | | |
| | (3.601) | | | |
| $HighIV_i$=1 × $Post_t$=1 | | −30.807$^{***}$ | | |
| | | (−4.058) | | |
| $HighO/S_i$=1 × $Post_t$=1 | | | −34.695$^{***}$ | |
| | | | (−4.427) | |
| $HighOmega_i$=1 × $Post_t$=1 | | | | 19.019$^{**}$ |
| | | | | (2.450) |
| Stock FE | Yes | Yes | Yes | Yes |
| Date FE | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.830 | 0.830 | 0.830 | 0.830 |
| Obs | 231,845 | 231,845 | 231,845 | 231,845 |

| Panel B: $\|RetCallBuy - RetCallSell_{it}\|$ | | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| $HighS_i$=1 × $Post_t$=1 | 0.543$^{***}$ | | | |
| | (3.289) | | | |
| $HighIV_i$=1 × $Post_t$=1 | | −0.617$^{***}$ | | |
| | | (−4.166) | | |
| $HighO/S_i$=1 × $Post_t$=1 | | | −0.775$^{***}$ | |
| | | | (−5.103) | |
| $HighOmega_i$=1 × $Post_t$=1 | | | | 0.246$^{*}$ |
| | | | | (1.683) |
| Stock FE | Yes | Yes | Yes | Yes |
| Date FE | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.578 | 0.578 | 0.579 | 0.578 |
| Obs | 294,769 | 294,769 | 294,769 | 294,769 |

**Table 11**
## Trading Fee Reduction and Stock Market Liquidity

This table shows how stock-market liquidity measures changed around RobinHood's introduction of free option trading. $QuotedSp_{it}$ ($EffectiveSp_{it}$) [$RealizedSp_{it}$] is the relative quoted (effective) [realized] bid-ask spread. $PriceImpact_{it}$ is the five-minute measure of price impact. $IncreasedORT_i$ is a dummy equal to one for the stock that experience a large increase in retail-option trading when RobinHood decreased fees on option trading and zero, otherwise. $Post_t$ is a dummy equal to one, after the decrease in fee, and zero, otherwise. We include stock- and date-fixed effects. $^{*}$, $^{**}$, and $^{***}$ indicate that parameters are significantly different from zero at the 10%, 5%, or 1% level, respectively. Standard errors are two-way clustered at the stock and date level. The sample consists of daily observation for 3,585 stocks between September 14, 2017 and March 13, 2018.

| | (1) $QuotedSp_{it}$ | (2) $EffectiveSp_{it}$ | (3) $RealizedSp_{it}$ | (4) $PriceImpact_{it}$ |
|---|---|---|---|---|
| $IncreasedORT_i$=1 × $Post_t$=1 | $-0.018^{***}$ | $-0.008^{***}$ | $-0.004^{**}$ | $-0.004^{*}$ |
| | (−3.825) | (−2.750) | (−2.265) | (−1.846) |
| Stock FE | Yes | Yes | Yes | Yes |
| Date FE | Yes | Yes | Yes | Yes |
| Adj. $R^2$ | 0.870 | 0.833 | 0.486 | 0.519 |
| Obs | 432,351 | 432,136 | 432,128 | 432,128 |

# Appendix

**Table A-1**
## Determinants of Increased Volatility and Retail Option Trading around RobinHood Cost Reduction

This table shows the increase in 5-minute stock price volatility, $Volatility_{it}$, and volume of 1-contract option trades, $RetailOVolume_{it}$, around RobinHood's introduction of free option trading. ....

Panel A: One-way sorts

| | by $O/S_i$ | | by $\frac{\Delta \cdot S}{O}$ | |
|---|---|---|---|---|
| | $Volatility_{it}$ | $RetailOVolume_{it}$ | $Volatility_{it}$ | $RetailOVolume_{it}$ |
| $Rank_i$=0 × $Post_t$=1 | 0.236*** | 0.155*** | −0.242*** | −0.148*** |
| $Rank_i$=1 × $Post_t$=1 | 0.242*** | 0.121*** | −0.111*** | −0.087*** |
| $Rank_i$=2 × $Post_t$=1 | 0.166*** | 0.044 | −0.046*** | −0.070*** |
| $Rank_i$=3 × $Post_t$=1 | 0.110*** | 0.041 | 0.028* | −0.004 |
| $Rank_i$=4 × $Post_t$=1 | | | | |

Panel B: Two-way sorts, by $IV_i$ (down) and $S_i$ (across)
$Volatility_{it}$

| | $RankS_i$=0 | $RankS_i$=1 | $RankS_i$=2 | $RankS_i$=3 | $RankS_i$=4 |
|---|---|---|---|---|---|
| $RankIV_i$=0 × $Post_t$=1 | −0.138 | 0.106*** | 0.089** | 0.191*** | 0.250*** |
| $RankIV_i$=1 × $Post_t$=1 | 0.231 | 0.047 | 0.084** | 0.231*** | 0.287*** |
| $RankIV_i$=2 × $Post_t$=1 | 0.084 | 0.089*** | 0.060* | 0.198*** | 0.212*** |
| $RankIV_i$=3 × $Post_t$=1 | 0.071*** | 0.052** | 0.034 | 0.155*** | 0.102* |
| $RankIV_i$=4 × $Post_t$=1 | | | | | |

Panel C: Two-way sorts, by $IV_i$ (down) and $S_i$ (across)
$RetailOVolume_{it}$

| | $RankS_i$=0 | $RankS_i$=1 | $RankS_i$=2 | $RankS_i$=3 | $RankS_i$=4 |
|---|---|---|---|---|---|
| $RankIV_i$=0 × $Post_t$=1 | 0.275*** | 0.196*** | 0.109 | 0.284** | 0.286*** |
| $RankIV_i$=1 × $Post_t$=1 | −0.025 | 0.192*** | 0.054 | 0.232** | 0.197** |
| $RankIV_i$=2 × $Post_t$=1 | 0.151 | 0.139** | 0.025 | 0.102 | 0.126 |
| $RankIV_i$=3 × $Post_t$=1 | 0.020 | 0.047 | −0.021 | 0.078 | 0.082 |
| $RankIV_i$=4 × $Post_t$=1 | | | | | |

Panel D: Two-way sorts, by $IV_i$ (down) and $S_i$ (across)
Frequency

| | $RankS_i$=0 | $RankS_i$=1 | $RankS_i$=2 | $RankS_i$=3 | $RankS_i$=4 |
|---|---|---|---|---|---|
| 0 | 4.000 | 59.000 | 130.000 | 180.000 | 275.000 |
| 1 | 5.000 | 84.000 | 134.000 | 210.000 | 217.000 |
| 2 | 17.000 | 150.000 | 163.000 | 171.000 | 149.000 |
| 3 | 118.000 | 245.000 | 163.000 | 86.000 | 38.000 |
| 4 | 457.000 | 110.000 | 50.000 | 19.000 | 13.000 |